

**"MODELING ULTRAVIOLET EMISSIONS
NEAR IO"**

NASW-99013

Final Report,

June 1, 1999–May 31, 2000

NASA CONTRACT: NASW-99013

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1. Introduction

In this report, we describe work performed under Contract NASW-99013, awarded to Science Applications International Corporation, for the period 6/1/99 to 5/31/00. During this time period, we have investigated the interaction of Io, Jupiter's innermost Galilean satellite, with the Io plasma torus, and the role this interaction plays in producing ultraviolet (UV) emissions from neutral oxygen and sulfur.

Io, the innermost of Jupiter's Galilean satellites, plays a unique role in the Jovian magnetosphere. Neutral material that escapes from Io is ionized to form the Io torus, a dense, heavy-ion plasma that corotates with Jupiter and interacts with Io. Io supplies not only the torus, but is a major source of plasma for the entire magnetosphere. Ionization and charge-exchange of neutrals near Io strongly influences the plasma interaction, and Io's neutral atmosphere plays an important role in the generation of currents that couple Io to Jupiter. There have been no *in situ* measurements of the neutral density near Io, but remote observations of neutrals near Io have been performed for many years [Brown, 1974; Trafton et al. 1974; Brown et al., 1983 and references therein].

Recent observations from the Hubble Space Telescope (HST) have shown detailed structure in UV emissions from neutral species near Io. Electron-impact of the neutrals by the Io torus plasma is the primary mechanism responsible for exciting these emissions. Previously, we have modeled the Io plasma environment using three-dimensional magnetohydrodynamic (MHD) simulations (Linker et al. 1998a), and we have shown that the interaction between Io and the plasma torus plays an important role in producing the morphology of the observed emissions (Linker et al. 1998bc). In the past year, we have extended these studies to use both UV observations and Galileo particle and field measurements to investigate the Io interaction.

2. Intrinsic Magnetization at Io

A key question raised by results from the original flyby of the Galileo spacecraft past Io (December 7, 1995) is whether or not Io is intrinsically magnetized. The question is not likely to be settled conclusively with the data from this flyby. The first of three new flybys of Io by Galileo was planned for October 11, 1999 (referred to as I24). In anticipation of this flyby, as well as a coordinated HST observing campaign, we used our MHD model to perform further studies of the plasma interaction at Io. We considered both magnetized and conducting models of Io to see if differences in the predicted UV emission, together with possible differences in the predicted plasma and magnetic field signatures for I24, might allow us to distinguish more clearly between the models.

In the original flyby of Io (referred to as J0), the Galileo spacecraft flew through Io's wake with a closest approach distance of 898 km. Both conducting and magnetized models of Io could qualitatively match many of the features observed in the Galileo data, including the large depression in magnetic field magnitude that was observed [Linker *et al.*, 1998]. The I24 trajectory passed by Io upstream and on the flanks of Io. From the point of view of simple potential (current-free) magnetic field models, one might expect that for an Ionian dipole moment approximately aligned with the local (Jovian) magnetic field one would see a depression in the local magnetic field both well upstream and downstream of Io. This would be in contrast to what is expected for a conducting Io, where draping of the magnetic field upstream of Io causes the local magnetic field strength to increase while the currents driven in the conducting region reduce the field strength downstream of Io. However, the situation at Io is more complicated, because even if Io does have an intrinsic magnetic field, significant ion pickup must also be occurring and this will cause slowing of the flow and draping of the magnetic field. It turns out that for reasonable ion pickup rates, the region of depressed magnetic field upstream of Io in the magnetized case is closely confined near Io and not likely to be penetrated significantly by the I24 flyby. Figure 1 shows a summary of predictions for the plasma and magnetic field measurements during the I24 flyby that were presented at the October 1999 DPS meeting [Linker *et al.*, 1999]. Given the poor constraints on parameters of the model (e.g., ion pickup rate, extent of the collisional ionosphere, strength and tilt of any intrinsic field) our results suggest that conclusive proof or refutation of an Io intrinsic magnetic field are not likely from the Galileo measurements during this encounter.

Comparison of Conducting and Magnetized Models of Io: Predictions for the Galileo I24 Flyby

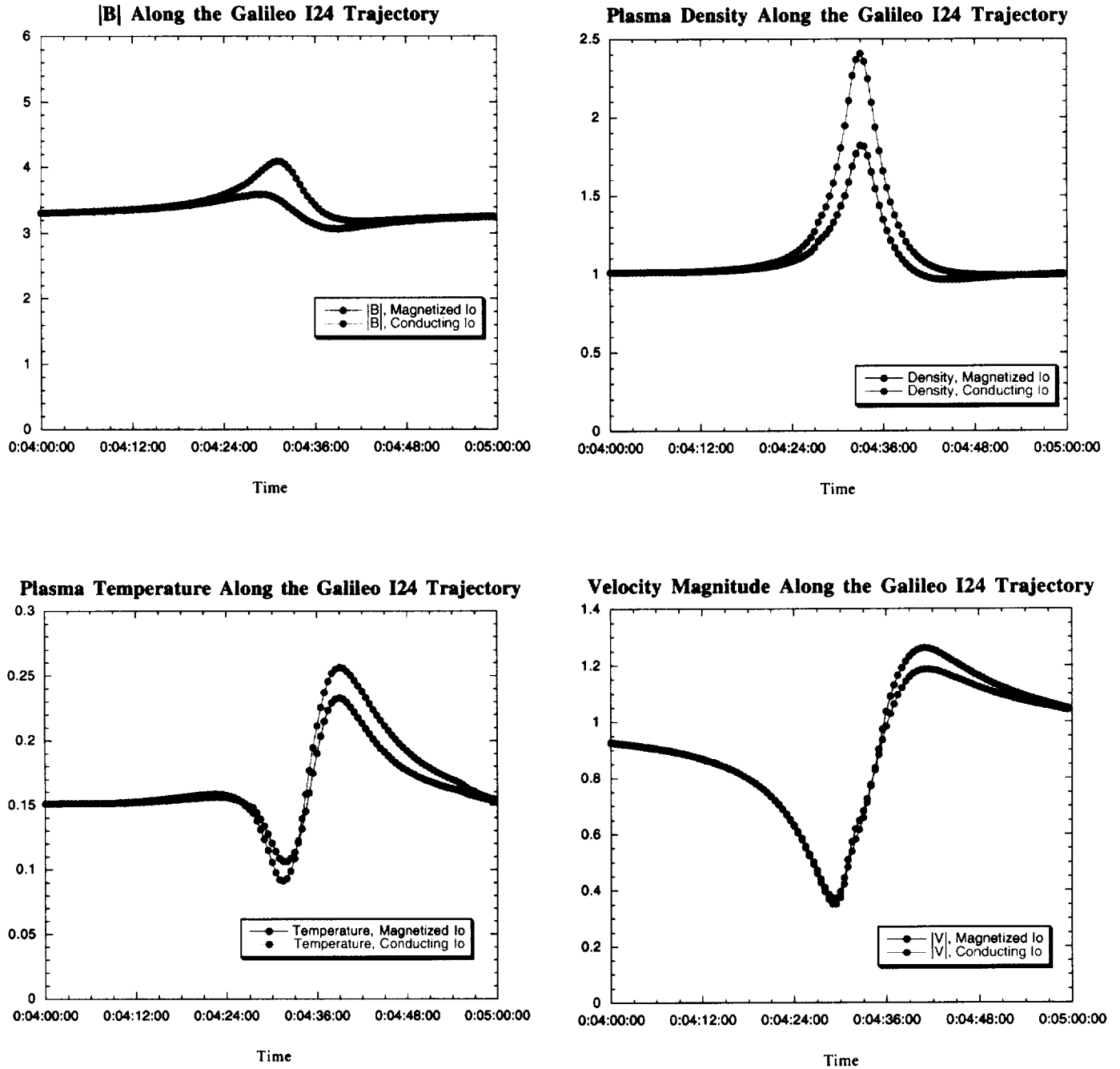


Figure 1. Comparison of predictions for the I24 flyby from conducting and magnetized models of Io.

To investigate whether UV observations from HST might reveal significant differences between the magnetized and conducting models of Io, we used the plasma properties from the MHD computations to simulate the observed emission for different viewing geometries. For collisional excitation of neutrals by electron impact, the apparent emission rate $4\pi J_\lambda$ can be written as an integral over the line of site:

$$4\pi J_\lambda = \int_{los} n_n(l) \epsilon(l) dl$$

where

$$\epsilon(l) = K \frac{n_e(l)}{\sqrt{T_e(l)}} \exp\left(-\frac{\Delta E}{T_e(l)}\right)$$

and n_n is the density of the neutral emitter, K is a constant related to the collision strength, n_e is the electron density, T_e is the electron temperature (in eV), and ΔE is the energy of the emitted photon (in eV). In the MHD computations, the plasma properties near Io are computed self-consistently for a given neutral density distribution (n_n). To compute the emission, we use n_n (assumed to be spherically symmetric), the plasma density, and the plasma temperature from the MHD simulation. T_e is assumed to be a fixed fraction of the total plasma temperature. We orient the simulation domain such that the plasma flow direction is along the direction of corotation and the background magnetic field is aligned with the local direction of Jupiter's magnetic field (at Io) at the time of the observation.

Because the UV emissions are a line-of-sight integrated quantity, their properties can depend strongly on the viewing geometry. Figure 2 shows the definition of Io longitudes with respect to views from Earth, and Figure 3 shows how the simulated emission appears for different Io phases for both a conducting model of Io (top panels) and a magnetized model of Io (bottom panels). When Io is near longitude 0 (behind Jupiter) or 180 (in front of Jupiter), both models predict that the brightest emission occurs on the downstream side of Io. Near elongation, the models predict that the brightest emission occurs on the flanks of Io; this pattern of emission was observed in images taken with the Space Telescope Imaging Spectrograph (STIS).

While there are systematic differences between the emission brightness predicted by the two models, the emission morphology is very similar. Because the brightness can be very sensitive to model assumptions (background plasma

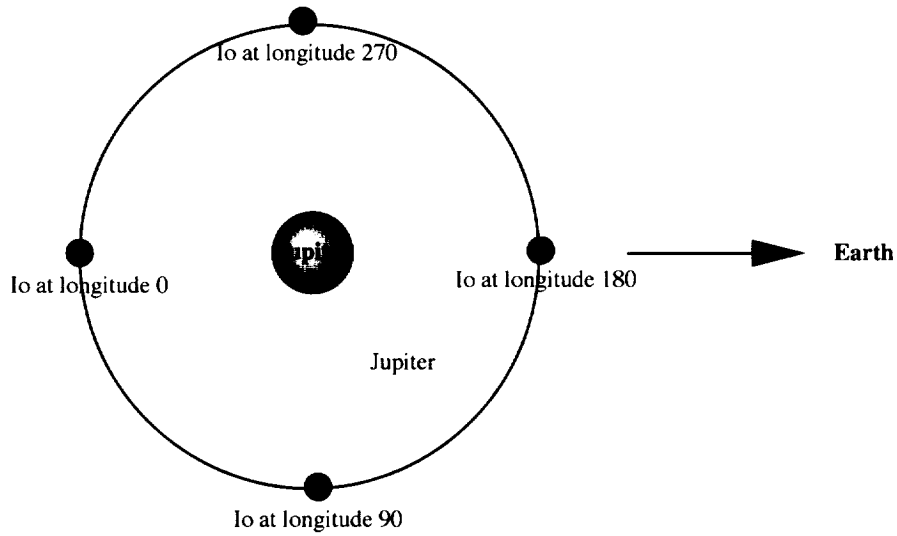


Figure 2. Definition of longitude positions for Io as viewed from Earth.

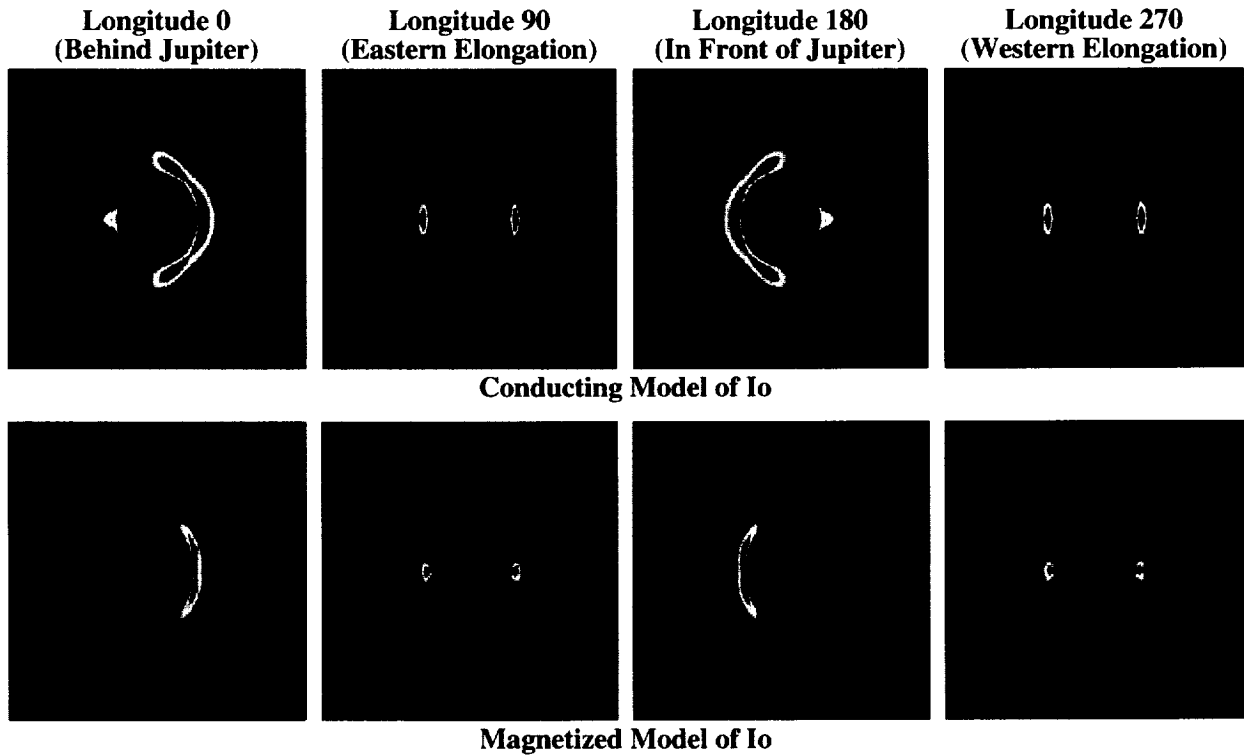


Figure 3. The variation of simulated planeofsky UV emission at 1356 Å (OI) as a function of Io's longitude for a conducting (top 4 panels) and magnetized (bottom 4 panels). The Io torus plasma corotates with Jupiter at 57 km/s faster than Io rotates. Therefore, at longitude 0, Io's wake is to the left and upstream of Io is to the right. At longitude 90, Io's wake is visible. At longitude 180, Io's wake is to the right and upstream of Io is to the left. At longitude 270, Io's upstream side is visible. The magnetized and conducting models show similar morphologies, but different emission brightnesses.

temperature and neutral density, for example), it will be difficult to distinguish between conducting and magnetized models on the basis of UV emission alone.

3. Comparison of Simulated and Calibrated UV Images

The techniques we have developed for computing simulated images can be used to compare our results with specific observations. Figure 4 shows an example of such a comparison for an HST STIS observation of OI (1356Å) taken on October 14, 1997. Figure 4a shows the local magnetic field geometry for the time of the observation. We use the viewing geometry at the time of the observation and compute the emission as in Figure 3. Figure 4b and 4c show a comparison between the STIS image and a simulated image generated with the plasma parameters from the MHD model. In the STIS image, we see that there is more intense emission on Io's flanks, there is a tilt of the emission in the plane (Io north is up), and there is higher emission on the northern part of Io relative to the south. These properties are all reproduced in the simulated image.

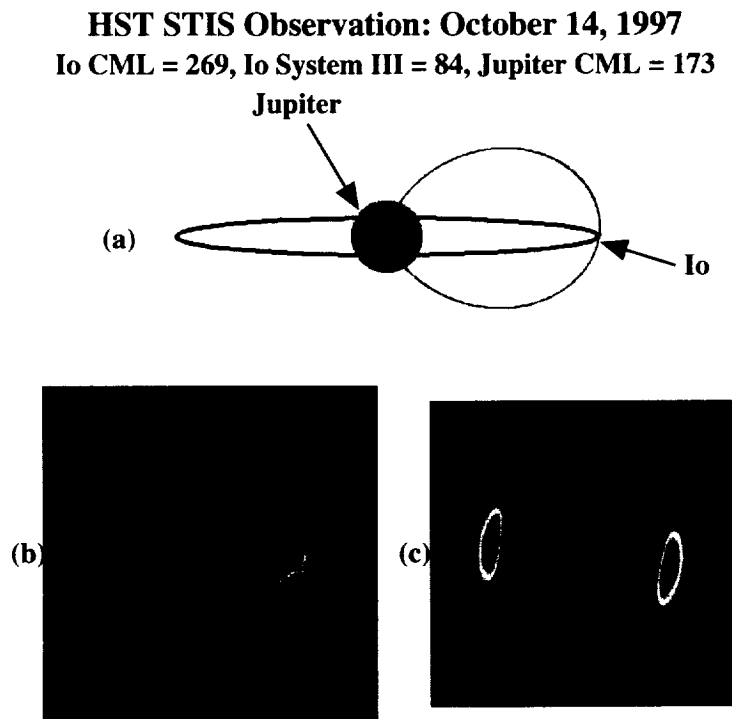


Figure 4. Comparison of a simulated emission image with a specific HST observation. (a) The geometry of a STIS observation taken on October 14, 1997. The orientation of a Jovian magnetic field line passing near Io is shown. (b) An HST STIS observation at 1356 Å (OI). The brightest emission is shown in red, the faintest emission is blue. (c) A simulated planeofsky image of UV emission at 1356 Å (OI) for the geometry shown. The image was created using the plasma density and temperature predicted by the MHD simulation, and a spherically symmetric neutral density.

We have performed a number of comparisons of our simulated images developed using the MHD model with HST observations (Linker et al. 1998bc, Linker, 1999; McGrath and Linker 1999). Many of the morphological features of the observations are reproduced in the simulated images, indicating the importance of Io's plasma environment in producing the UV emissions from neutral species. However, these comparisons were qualitative in nature, in that the observations were not all calibrated and only a relative brightness was computed for the simulated images. To perform a more quantitative comparison, we have developed a calibrated image for a specific STIS observation and also computed the absolute brightness.

Figure 5 shows a comparison of a calibrated HST STIS image with the absolute brightness predicted by the MHD simulation. Note that the model matches the morphological features of the observation reasonably well. In particular, the high intensity "spots" on the limbs and their tilt relative to Io's equator are present in both the model and the observations, and the spot on the Jupiter side of Io has slightly less intensity. When the images are scaled exactly the same, we see that the peak emission predicted by the model is about 50% less than that obtained in the calibrated image. Given the uncertainties in many parameters (such as the neutral density at Io), the agreement is quite good.

The results from our MHD computations of the Io interaction and comparisons with both Galileo data and HST observations of UV emission show that the models can reproduce many features of the observations. Our models suggest that much of the structure in the UV emissions from neutrals species near Io can be explained as a production of the interaction of the Io torus plasma with Io's atmosphere and exosphere. Even with an assumption of a spherically symmetric exosphere, the "spot-like" features on the flanks of Io that have been consistently observed when Io is near elongation are reproduced. While Io's atmosphere may in actuality have significant departures from spherical symmetry, our results suggest that particular asymmetric features of the atmosphere are not essential for producing the observed emission features.

HST STIS Observation: October 14, 1997
Io CML = 243, Io System III = 357, Jupiter CML = 60

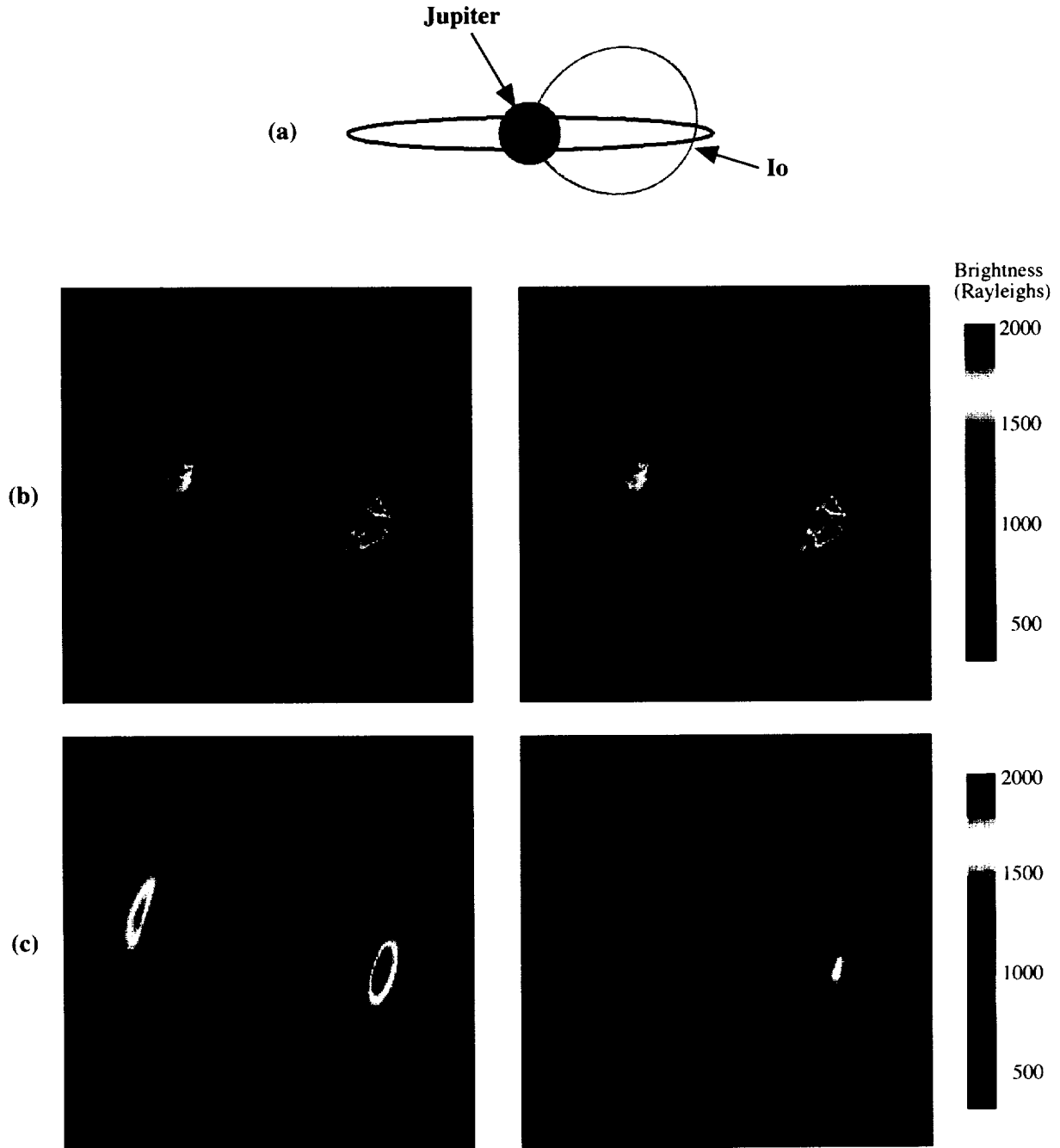


Figure 5. Comparison of a calibrated HST STIS image with absolute brightness predicted from the MHD model. (a) The geometry of the STIS observation. The orientation of a Jovian magnetic field line passing near Io is shown. Note that Io was not yet at elongation (in contrast to the case shown in Figure 4). (b) An HST STIS observation at 1356 Å (OI). The image on the left shows the approximate position of Io as a red circle. (c) A simulated planeofsky image of UV emission at 1356 Å (OI) for the geometry shown. The absolute brightness was computed using the plasma density and temperature predicted by the MHD simulation. The image on the left is scale between 140 and 1600 Rayleighs (the approximate range for the predicted emission, while the image on the right is scaled exactly the same as the STIS image (300 to 2000 Rayleighs)).

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- *Supported by NASA Planetary Atmospheres. A manuscript summarizing these results is in preparation.

| REPORT DOCUMENTATION PAGE | | | Form Approved OMB No. 0704-0188 | |
|--|---|--|--|--|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20506. | | | | |
| 1. AGENCY USE ONLY (Leave Blank) | | 2. REPORT DATE October 17, 2000 | | 3. REPORT TYPE AND DATES COVERED Final Report 6/1/99-5/31/00 |
| 4. TITLE AND SUBTITLE Modeling Ultraviolet Emissions Near Io: Final Report | | | 5. FUNDING NUMBERS NASW-99013 | |
| 6. AUTHORS Jon Linker | | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Science Applications International Corporation 10260 Campus Point Drive MS A1P San Diego, CA 92121-1578 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER SAIC-00/8030:APPAT-263 01-0157-04-0340-000 | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) NASA Center for Aerospace Information (CASI) 7121 Stanford Drive Hanover, MD 21076 | | | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER | |
| 11. SUPPLEMENTARY NOTES | | | | |
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT NTIS | | | 12b. DISTRIBUTION CODE NTIS | |
| 13. ABSTRACT (Maximum 200 words) This report describes our work in understanding ultraviolet emissions near Io and their relationship to the Io plasma environment. | | | | |
| 14. SUBJECT TERMS Jupiter, Galilean, Plasma Flow, Magnetohydrodynamics | | | 15. NUMBER OF PAGES 3 | |
| | | | 16. PRICE CODE | |
| 17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED | 18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED | 19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED | 20. LIMITATION OF ABSTRACT UL | |

